AC INDUCTIVE CIRCUITS

Unclassified

3 Hour Conference, W/ 4Hr PE1

Safety & Environmental Impact is “[illegible]W”

Terminal Learning Objective

ACTION:

Calculate for Inductive Reactance, Impedance & the operating parameters of an RL type Ckt.

CONDITIONS:

With Official OMEMS Training Aid reference.

STANDARD:

7 of 10 answers must be.

Introduction

In previous lessons we dealt with the resistor as the opposition to the flow of current. In this lesson we will look at our 1st frequency sensitive component. The value of opposition will change with the change in frequency.

The Inductor is, a reactive component & nce its opposition cannot be easured, it must be calculated.

AC: Inductive Circuits

INDUCTOR;

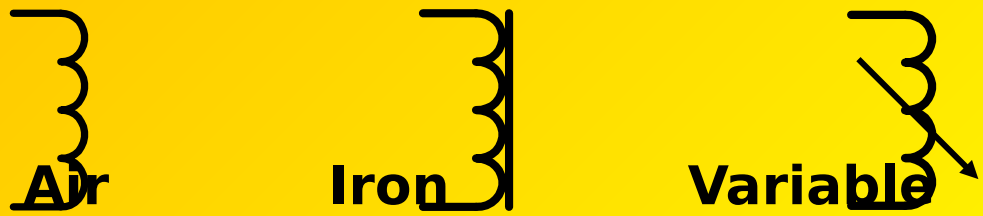
Opposes any <u>change</u> in Current & stores energy in an Electromagnetic Field.

It may be called a Choke or a Coil.

Inductor Symbol; **L**

Unit of Measure; **henrys**, **h** ***lower case*** , **mh** **milli henrys**

Schematic;



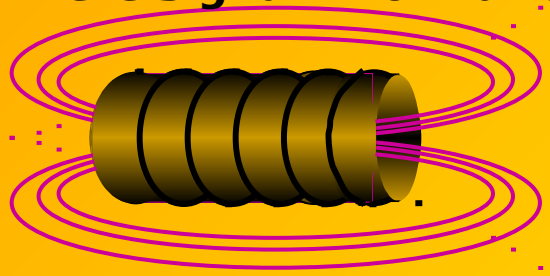
Air **Iron** **Variable**

Fe, Ferrite

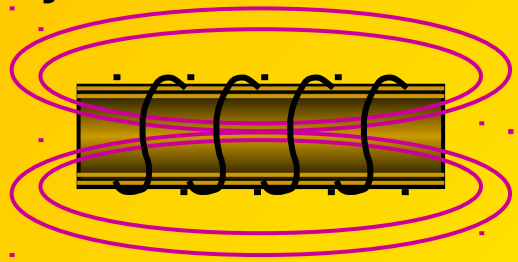
Air/ Iron core

Iron core versus Air core;

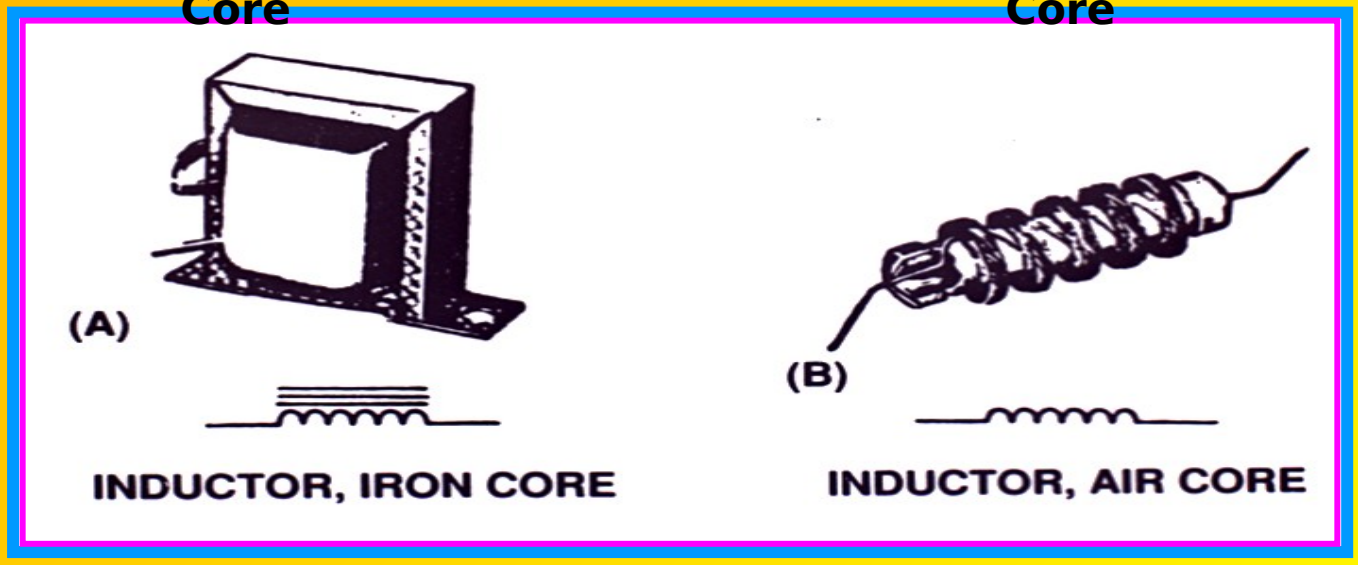
Iron is used in low frequency & power applications. Iron increases the permeability or strength of the magnetic fields. The Air Core is used in high frequency applications, where signal information has priority.



Iron Core



Air Core

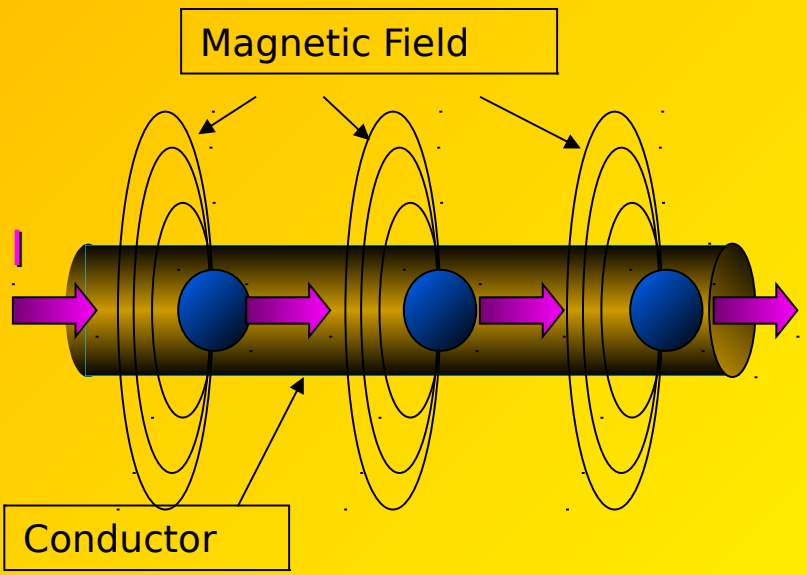


Magnetic Field;

As Current flows through a conductor a magnetic field is produced.

By winding a conductor in a small area and concentrating the magnetic field, an Inductor is produced.

The factors that determine the value of an Inductor are assembled & calculated mathematically.



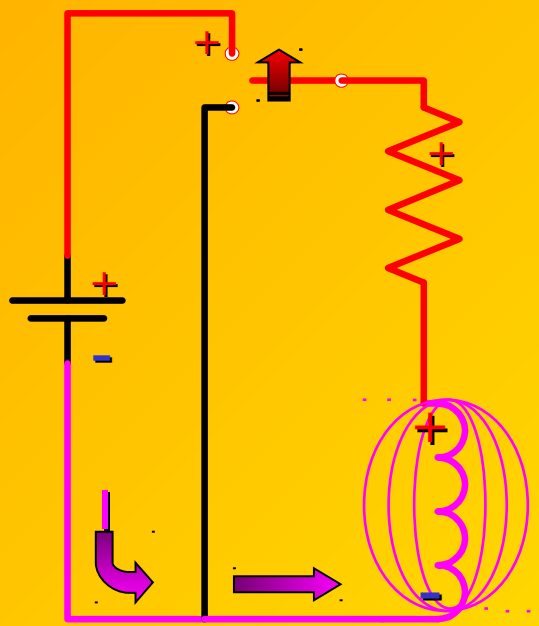
Expansion/ Contraction

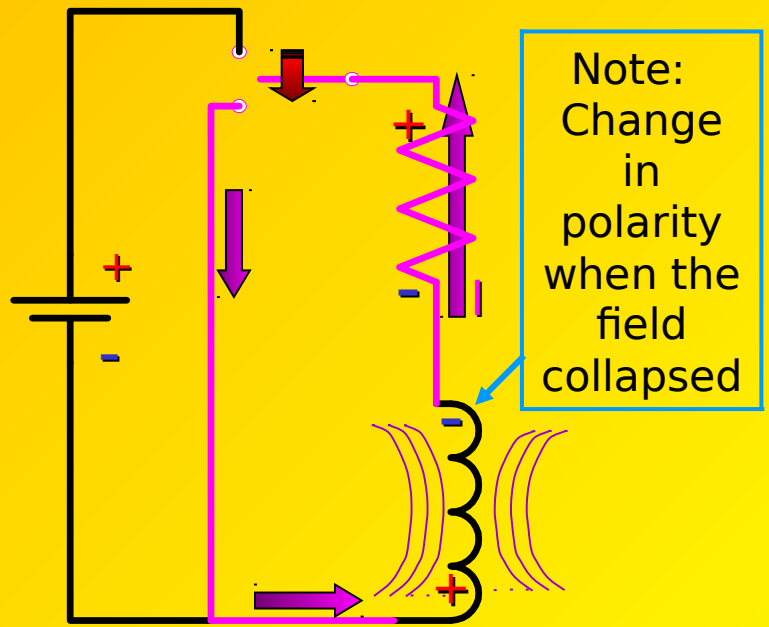
AC: Inductive Circuits

Induce or Induct;

Is the ability of an inductor to store energy in an electromagnetic field and return that energy to the Ckt, in the form of Current.

This ability is dependent upon change; AC offers that change.





Note: Change in polarity when the field collapsed

AC Inductor Action

AC: Inductive Circuits

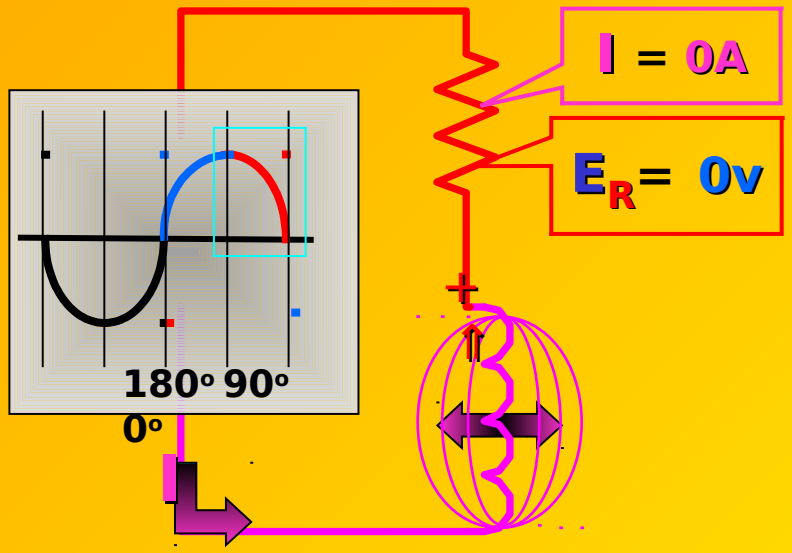
Induce or Induct;

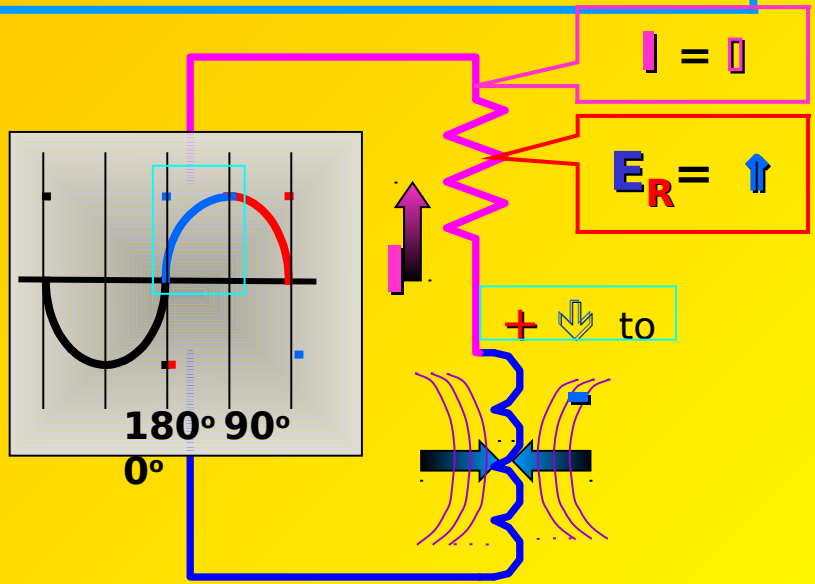
The Inductor function is dependent upon change. (AC)

It will convert Current Energy to Electromagnetic energy.

Then the Electromagnetic energy back to Current.

The energy change occurs w/the change in polarity of the AC.

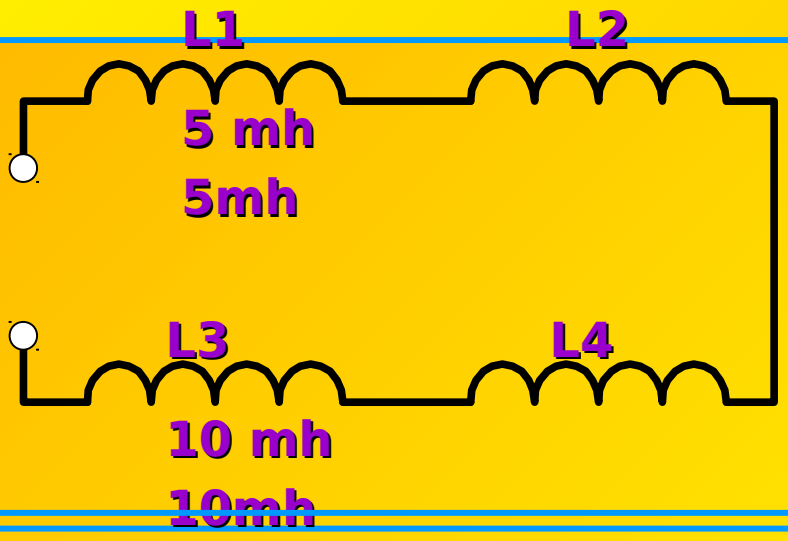




Series

<u>Inductors in Series</u> are Additive like resistors in Series.

$$L_1 + L_2 + L_3 + L_4 \ldots = L_T$$



$L_1 + L_2 + L_3 + L_4 = L_T$

5 mh + 5mh + 10 mh + 10 mh = 30

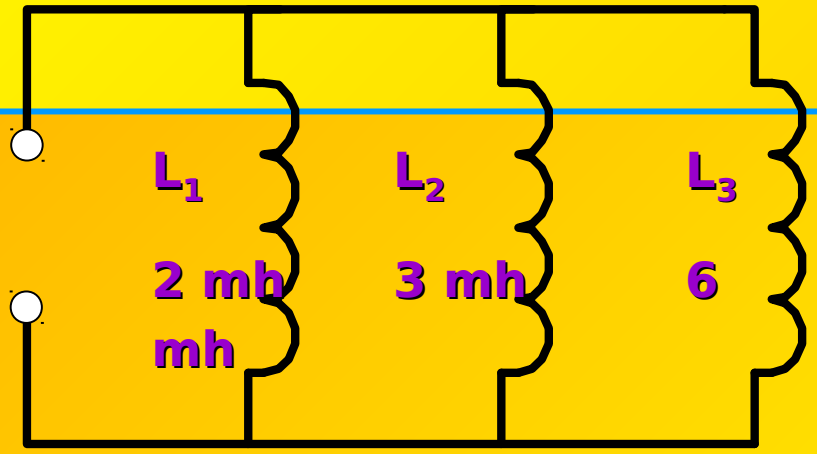
Parall
el

Inductors in Parallel are calculated like resistors in Parallel.

Like Value, Product over the Sum & Reciprocal methods.

The LEQ will be smaller than the smallest value Inductor in the Parallel Ckt. [L_{EQ} < 2 mh]

$$L_1\ 1/X + L_2\ 1/X + L_3\ 1/X \ldots = 1/X \Rightarrow L_{EQ}$$



NOTE:

The LEQ & LT will be the same in a Pure Parallel Ckt.

2 mh 1/X + 3 mh 1/X + 6 mh 1/X = 1/X ⇒ 1 mh

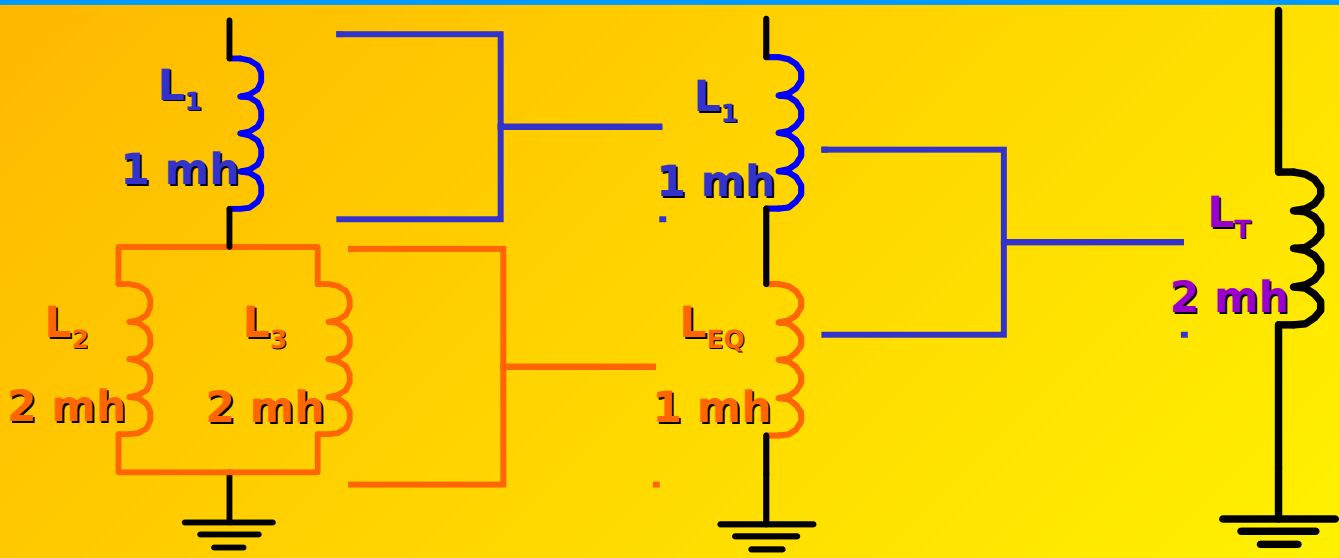
Series & Parallel

Inductors in Series Parallel are calculated like resistors in a Series Parallel Ckt.

Like Resistors, this will reduce the Ckt values down to a single value of Inductance Total, LT.

Calculate the LEQ then Add the Inductors in series.

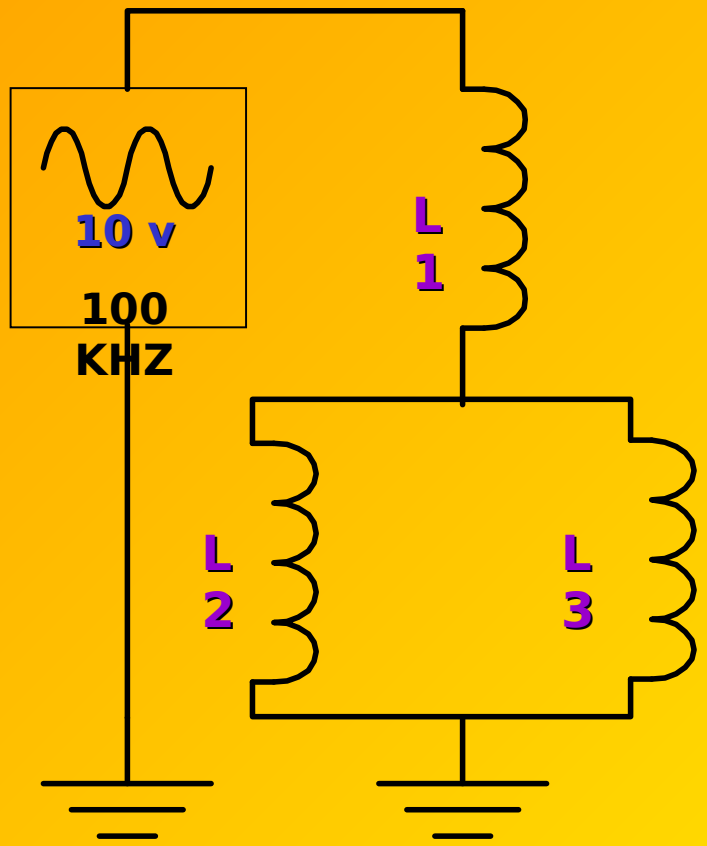
$$L_{EQ} + L_1 = L_T$$



Challenge

AC: Inductive Circuits

Calculate values for LEQ, LT, Period & Pulse Width.



A.

L1 = 10 mh
L2 = 30 mh
L3 = 30 mh

EA = _____
LEQ = ____
LT = _____
P = _____
PW = ____

B.

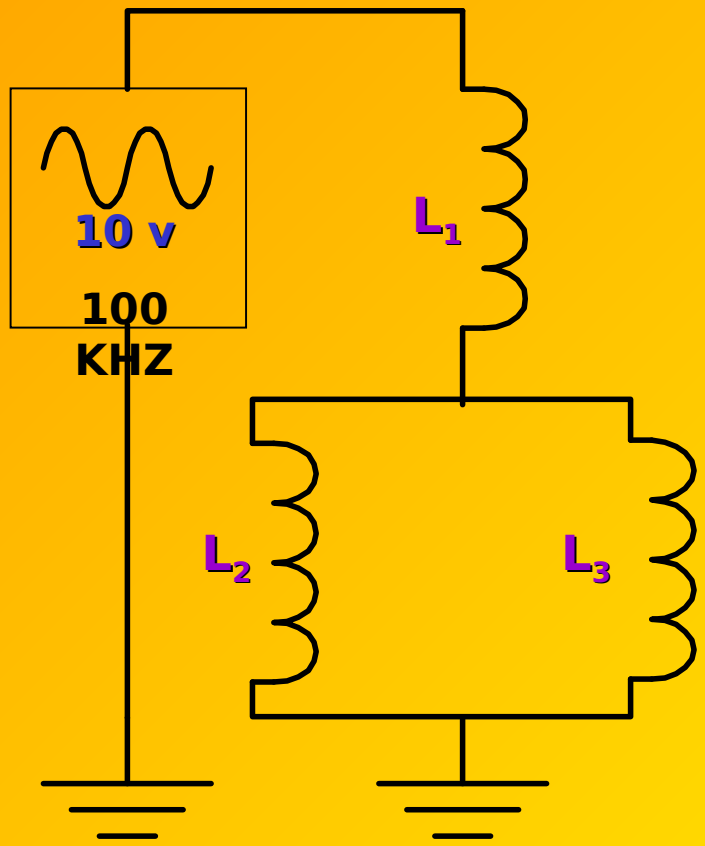
L1 = 3 mh
L2 = 4 mh
L3 = 5 mh

EA = _____
LEQ = ____
LT = _____
P = _____
PW = ____

Answers

AC: Inductive Circuits

Calculated values for LEQ, LT, Period & Pulse Width.



A.

L1 = 10 mh	EA = 10 v
L2 = 30 mh	LEQ = 15 mh
L3 = 30 mh	LT = 25 mh
P = Freq 1/X	P = 10 μ S
	PW = 5 μ S

B.

L1 = 3 mh	EA = 10 v
L2 = 4 mh	LEQ = 2.22 mh
L3 = 5 mh	LT = 5.22 mh
PW = ½ P	P = 10 μ S
	PW = 5 μ S

XL

Reactance;

Because the Inductor is a Frequency sensitive device, it will change in value of opposition as the Frequency changes. Since its value cannot be measured, it has to be calculated, with frequency as part of the equation.

Reactance, Symbol; X **Unit of Measure; Ω Ohms**

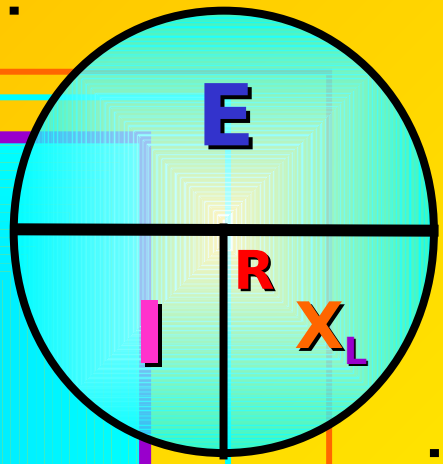
Inductive Reactance; X_L **Unit of Measure; Ω**

$X_L =$

"2 Pies For Lunch"

2 π F L

2 π X Frequency X Inductor



X_L =

“2 Pies For Lunch”

2 π F L

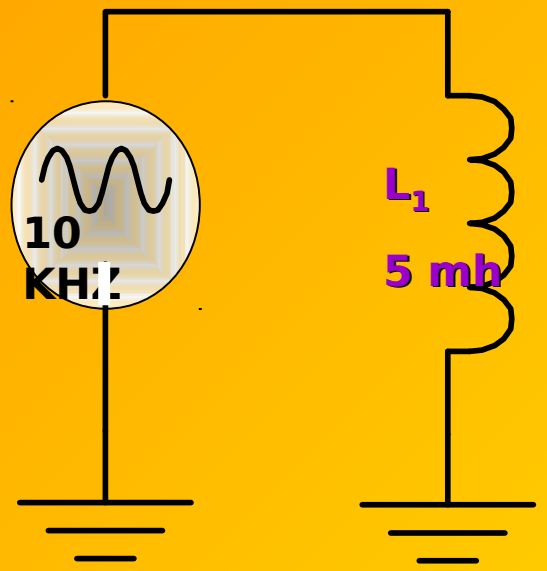
2 π x Frequency **x I**nductor

6 .28 x Freq x Ind. = XL in Ω

Ω

AC: Inductive Circuits

Inductive Reactance;



$2 \pi F L$

6 .28 X Freq X Ind. = X_L in Ω

6.28 X 10 KHZ X 5 mh = X_L

XL = 314 Ω

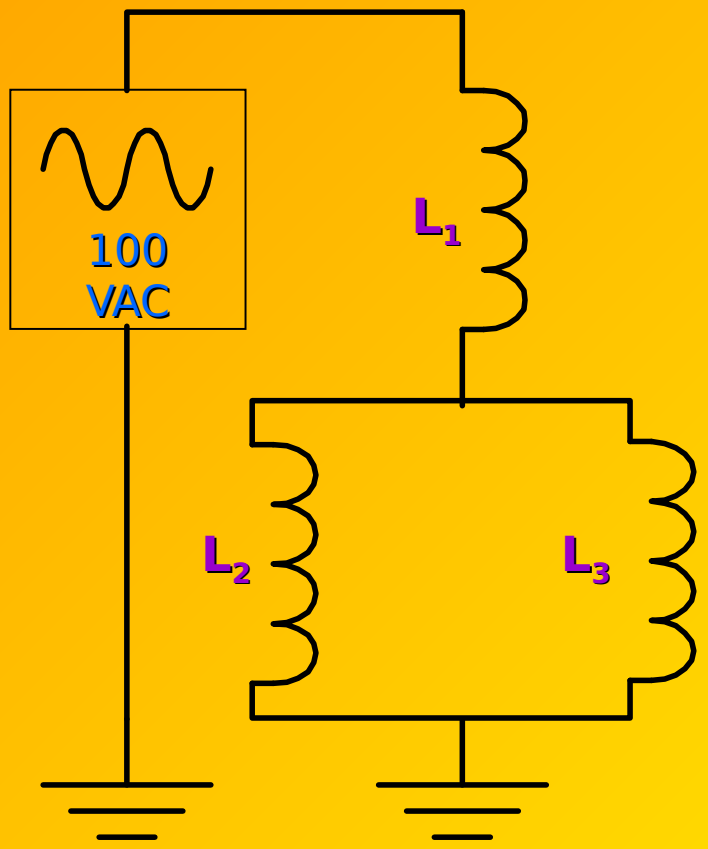
On the Calculator;

6.28 X 10 EE³ X 5 EE⁻³ = 314 Ω

Challenge

AC: Inductive Circuits

Calculate the values of LEQ, LT, XLT. [No Rounding & carry Decimal 2 places].



$2 \pi F L$

6 .28 X Freq X L_T = X_{LT} in Ω

A.

L1 = 3 mh	EA = _____
L2 = 4 mh	LEQ = ____
L3 = 5 mh	LT = _____
Freq = 8 KHZ	XLT = ____

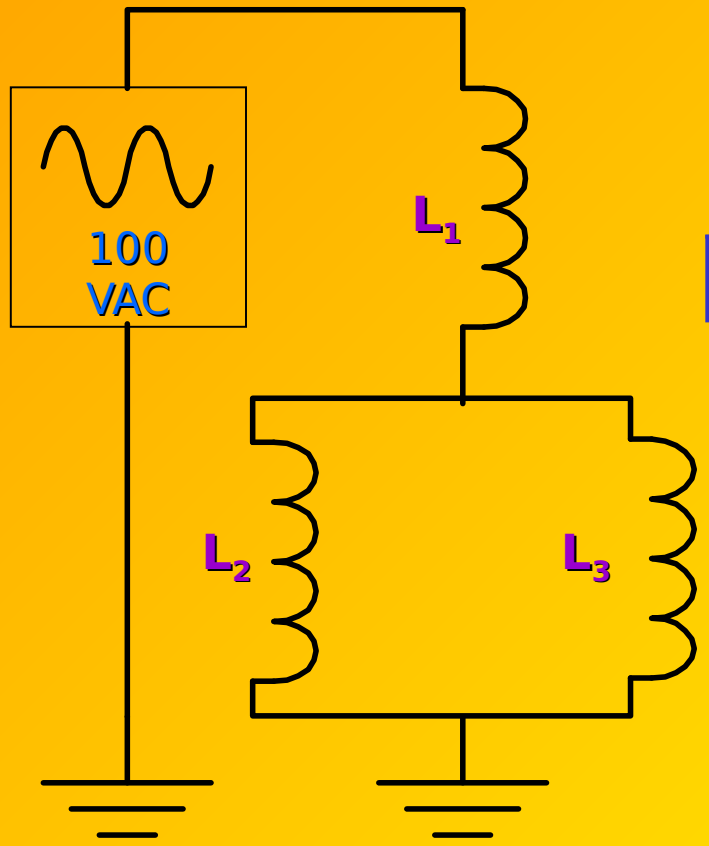
B.

L1 = 3 mh	EA = _____
L2 = 5 mh	LEQ = ____
L3 = 6 mh	LT = _____
Freq = 10 KHZ	XLT = ____

Answers

AC: Inductive Circuits

Calculate the values of LEQ, LT, XLT. [No Rounding & carry Decimal 2 places].



$2 \pi F L$

6 .28 X Freq X L_T = X_{LT} in Ω

A.

L1 = 3 mh	EA = 100 V
L2 = 4 mh	LEQ = 2.22 mh
L3 = 5 mh	LT = 5.22 mh
Freq = 8 KHZ	XLT = 262.25 Ω

B.

L1 = 3 mh	EA = 100 V
L2 = 5 mh	LEQ = 2.72 mh
L3 = 6 mh	LT = 5.72 mh
Freq = 10 KHZ	XLT = 359.21 Ω

Challenge

Calculate the value of X_L . [No Rounding].

$2 \pi F L$

6 .28 X Freq X L_T = X_{LT} in Ω

F = 6 KHZ L_1 = 3mh X_{L1} = _____

F = 8 KHZ L_1 = 3mh X_{L1} = _____

F = 10 KHZ L_1 = 3mh X_{L1} = _____

F = 10 KHZ L_1 = 5mh X_{L1} = _____

F = 10 KHZ L_1 = 8mh X_{L1} = _____

F = 10 KHZ L_1 = 10mh X_{L1} = _____

6.28 X F EE^3 X L EE^{-3} = X_{L1}

Answers

AC: Inductive Circuits

Calculate the value of X_L . [No Rounding].

Relationship; A DIRECT RELATIONSHIP exists between the XL and Frequency and the size or (value of the Inductor).

$2 \pi F L = X_L$ in Ω

X_L in Ω ⇧ Then E_L ⇧

F = 6 KHZ	L_1 = 3mh	X_{L1} = 113 Ω
F = 8 KHZ	L_1 = 3mh	X_{L1} = 150.72 Ω
F = 10 KHZ	L_1 = 3mh	X_{L1} = 188.4 Ω
F = 10 KHZ	L_1 = 5mh	X_{L1} = 314 Ω
F = 10 KHZ	L_1 = 8mh	X_{L1} = 502.4Ω
F = 10 KHZ	L_1 = 10mh	X_{L1} = 628. Ω

NOTE:

DIRECT RELATIONSHIPs.

As the **Frequency** ⇧ the XL ⇧ also.

As the **Inductor** ⇧ the XL ⇧.

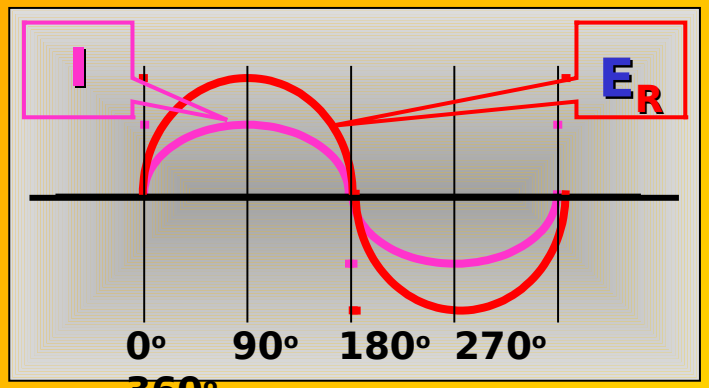
Phase

AC: Inductive Circuits

Phase Relationship;

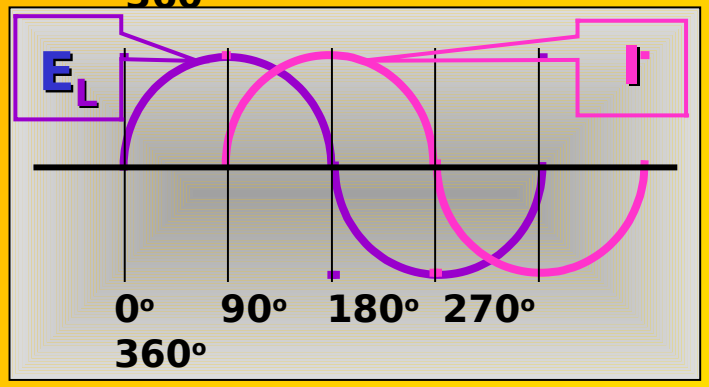
The relation between Voltage across the Inductor and Current through the Inductor.

"Voltage Leads Current By 90°"



In Phase;

Voltage across a Resistor "ER" & Current "I".



90° out of Phase;

Voltage across an Inductor "EL" leads Current "I" by 90°.

Vector

AC: Inductive Circuits

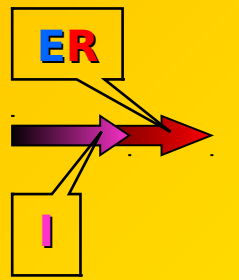
Phase Relationship;

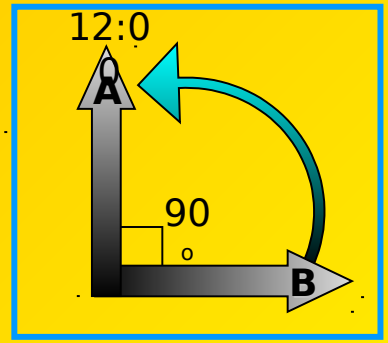
Voltage Leads Current By 90º

E L I the ICE man is 90 years old.

In Phase VECTOR Illustration.

Voltage across a Resistor "ER" & Current "I".

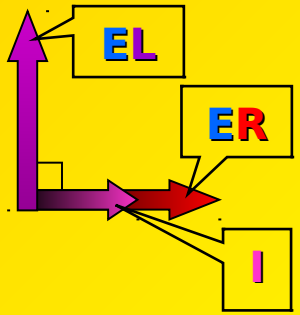




90º Out of Phase VECTOR Illustration.

Voltage across an Inductor "EL" leads Current "I" by 90º.

Or **"I" Lags the "EL" by 90º.**



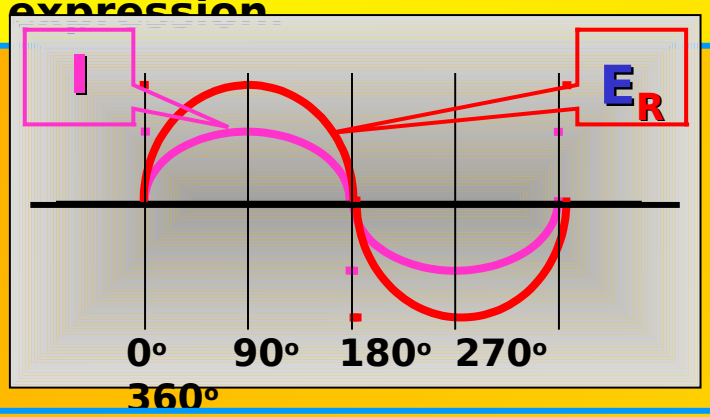
AC: Inductive Circuits

Phase Relationship; The Sine & Vector illustrate the same Concept.

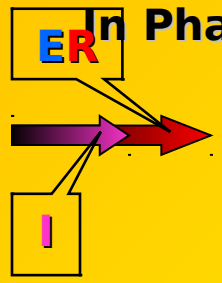
Voltage Leads Current By 90º

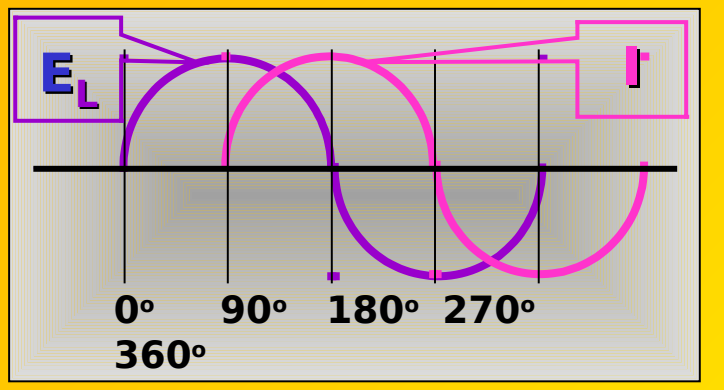
Sine; O-Scope Display.

Vector; Mathematical expression

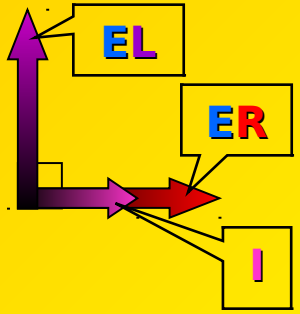


VECTOR Illustration;
In Phase

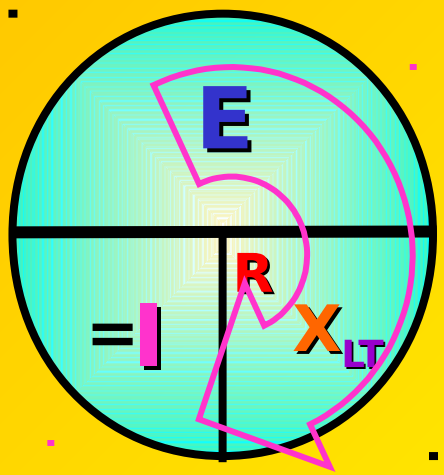




VECTOR Illustration;
90º Out of Phase



The Lag time of current is due to the expansion of the magnetic field

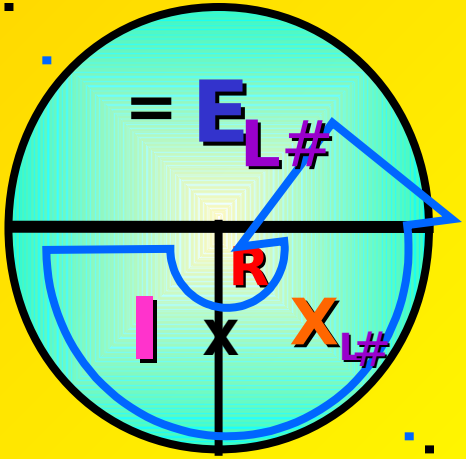


Current & Voltage Drops;

In a Purely Inductive Ckt
[a Ckt w/Inductors only].

Values can be calculated using Ohms Law $E_A \div X_{LT} = I_T$

$I_T \times X_{L\#} = E_{L\#}$



*It is very **unlikely** to have a purely Inductive Ckt.*

IMPEDANCE;

TOTAL OPPOSITION to the flow of AC Current.

In a Ckt containing more than one type of opposition.

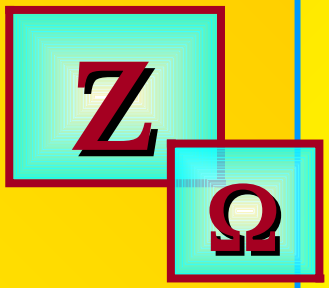
Non-reactive component, does not change value w/ the change in frequency**,** a Resistor.

Reactive component, changes value {XL} w/ the change of frequency; An Inductor.

IMPEDANCE;

TOTAL OPPOSITION must be calculated.

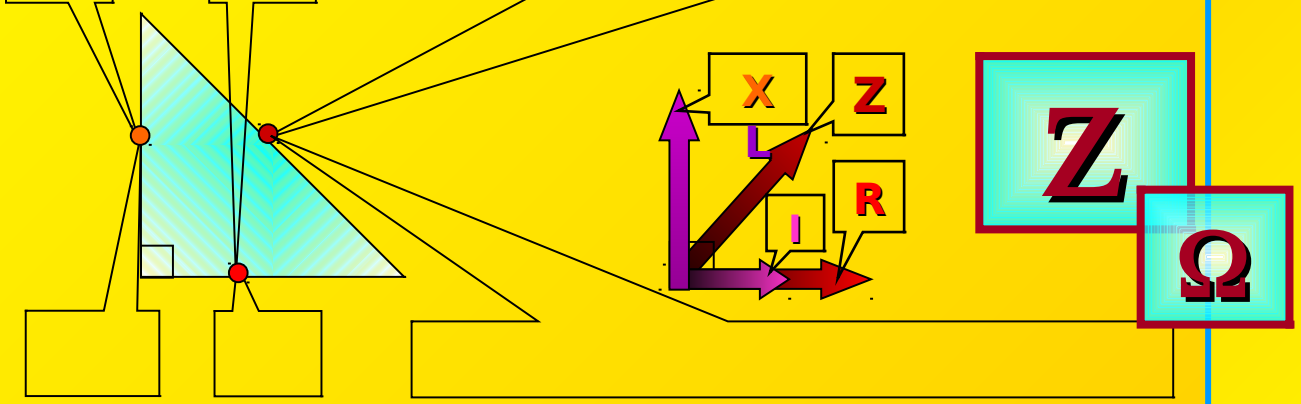
Symbol; Z Unit of Measure; Ω



IMPEDANCE;

Calculate total opposition by using Pythagoreans Theorem, referred to as Vectored Addition.

It States; $A^2 + B^2 = C^2$ is the Hypotenuse of a Triangle.



Restated; $XL^2 + R^2 = Z^2$ is the Hypotenuse of a Triangle.

R X + XL X = IX ⇒ Z in Ω

Challenge

AC: Inductive Circuits

IMPEDANCE; Calculate Impedance.

$$Z = \sqrt{R_T^2 + X_{LT}^2}$$

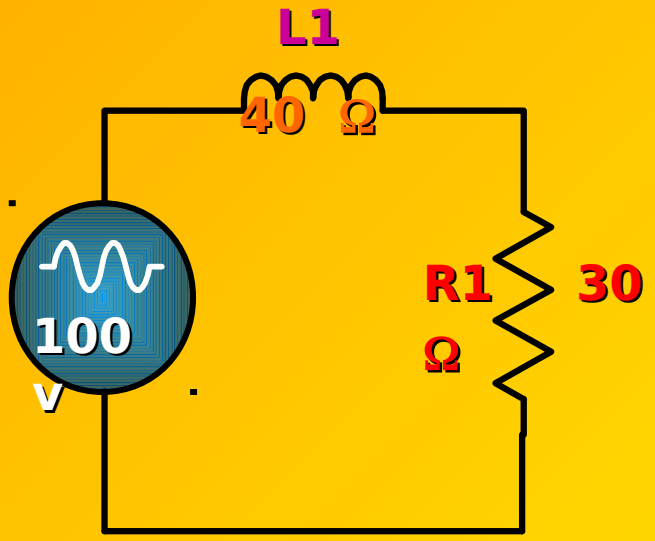
Z

Ω

Calculator:

R X^2 + XL X^2 = $\sqrt{\ }$ X ⇒

Z in Ω



EA = ____

Z_T = ____ $\sqrt{30^2 + 40^2}$

I_T = ____ EA ÷ ZT

E_{R1} = ____ I_T X R_1

E_{L1} = ____ I_T X X_{L1}

Answers

IMPEDANCE; Calculate Impedance.

$$Z = \sqrt{R_T^2 + X_{LT}^2}$$

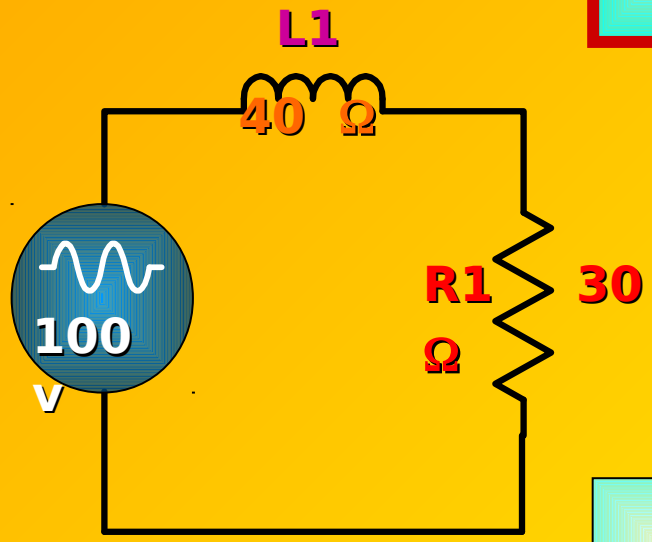
Z

Ω

Calculator:

R X^2 + XL X^2 = $\sqrt{\ }$ X ⇒

Z in Ω



EA = 100 v

Z_T = 50 Ω $\sqrt{30^2 + 40^2}$

I_T = 2 A EA ÷ ZT

E_{R1} = 60 v I_T X R_1

E_{L1} = 80 v I_T X X_{L1}

30 X^2 + 40 X^2 = 2500 $\sqrt{\ }$ X ⇒ 50 Ω

NOTE:

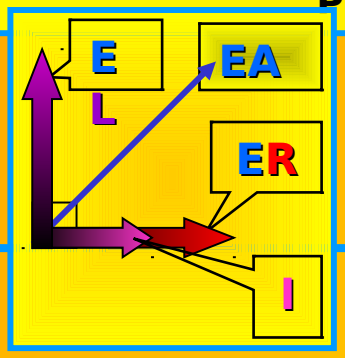
ER1 + EL1 will not = EA, *the opposition was calculated Vectorally*.

EA

AC: Inductive Circuits

EA; ER1 + EL1 will not = EA, The opposition was calculated Vectorally. Therefore the Voltage drops must be calculated Vectorally.

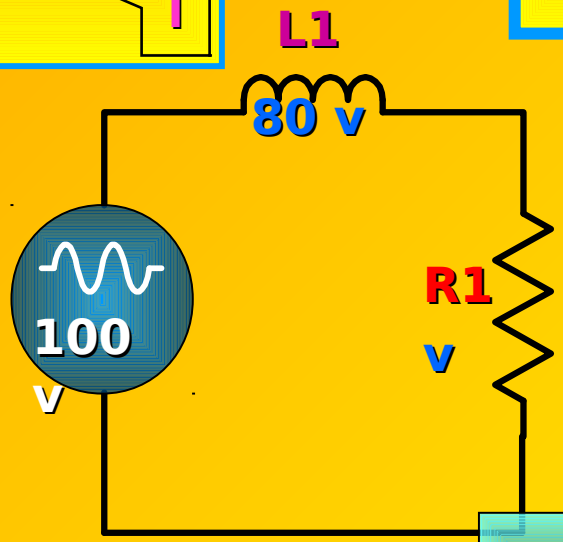
Pythagorean Theorem is used to solve total opposition



$$EA = \sqrt{E_{RT}^2 + E_{LT}^2}$$

Calculator;

E_R X^2 + E_L X^2 = $\sqrt{X}$ ⇒



EA =	100 v		
Z_T =	50 Ω	$\sqrt{30^2 + 40^2}$	
I_T =	2 A	EA ÷ ZT	
E_{R1} =	60 v	I_T X R_1	
E_{L1} =	80 v	I_T X X_{L1}	

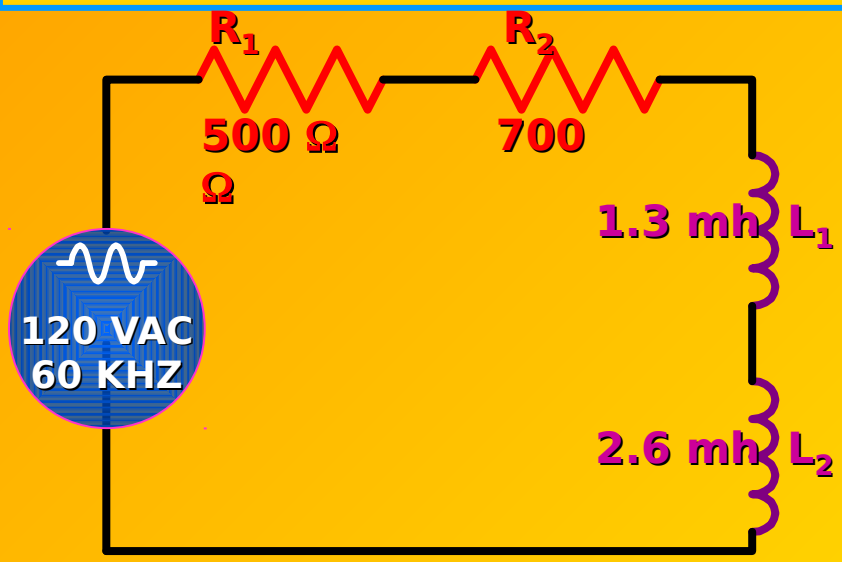
60 X^2 + 80 X^2 = 10000 X ⇒

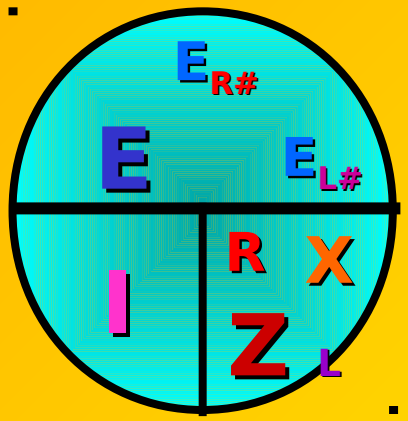
100 v

Challenge

AC: Inductive Circuits

Calculate The Normal Operating Parameters. [**No** Rounding, Decimal 3 Places].





Period = _____

PW = _____

$2\pi F L_1 =$ $X_{L1} =$ _____

$2\pi F L_2 =$ $X_{L2} =$ _____

$2\pi F L_T =$ $X_{LT} =$ _____

$R_1 + R_2 =$ $R_T =$ _____

$\sqrt{R_T^2 + X_{LT}^2} =$ $Z_T =$ _____

$EA \div Z =$ $I_T =$ _____

$I_T \times R_1 =$ $E_{R1} =$ _____

$I_T \times R_2 =$ $E_{R2} =$ _____

$E_{R1} + E_{R2} =$ $E_{RT} =$ _____

$I_T \times X_{L1} =$ $E_{L1} =$ _____

$I_T \times X_{L2} =$ $E_{L2} =$ _____

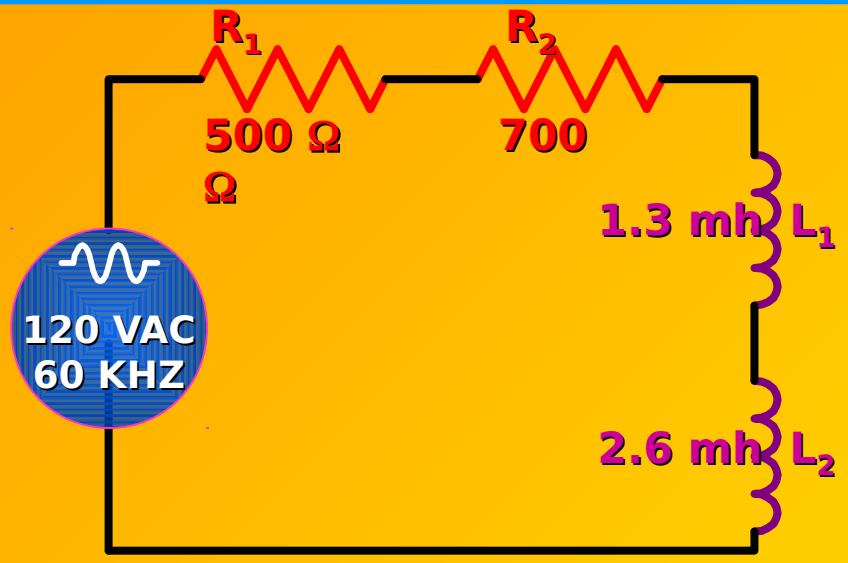
$\sqrt{E L_1 + E L_2} =$ $E_{LT} =$ _____

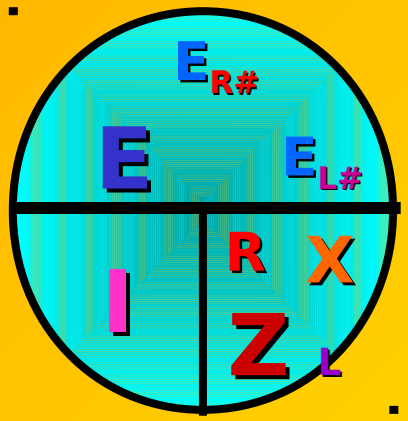
$E_{RT}^2 + E_{LT}^2 =$

XL1,2,3

AC: Inductive Circuits

Calculate The Normal Operating Parameters. [NO Rounding, Decimal 3 Places].





Period = 16.666 μS

PW = 8.333 μS

$2\pi F L_1 = X_{L1} = 489.84\ \Omega$

$2\pi F L_2 = X_{L2} = 979.68\ \Omega$

$2\pi F L_T = X_{LT} = 1.469\ K\Omega$

$R_1 + R_2 = R_T =$ _____

$\sqrt{R_T^2 + X_{LT}^2} = Z_T =$ _____

$EA \div Z =$ $I_T =$ _____

$I_T \times R_1 = E_{R1} =$ _____

$I_T \times R_2 = E_{R2} =$ _____

$E_{R1} + E_{R2} = E_{RT} =$ _____

$I_T \times X_{L1} = E_{L1} =$ _____

$I_T \times X_{L2} = E_{L2} =$ _____

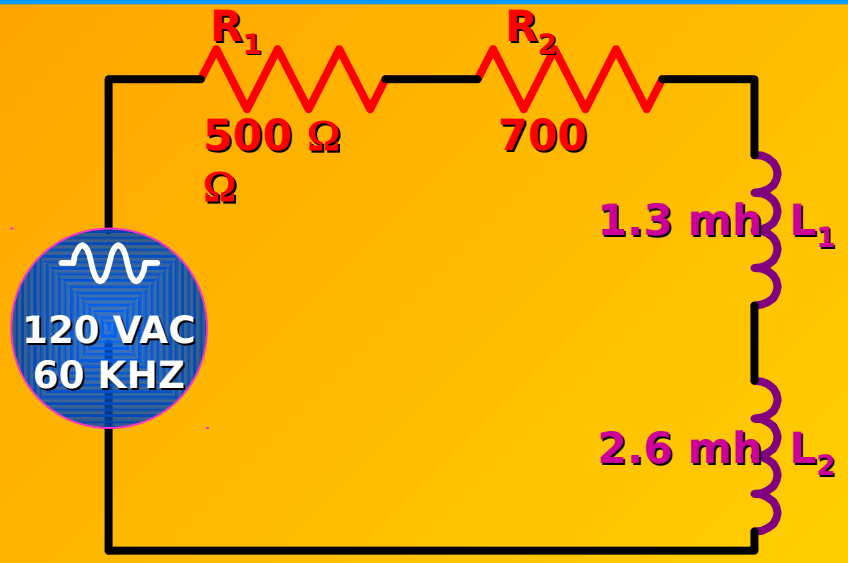
$\sqrt{E L_1 + E L_2} = E_{LT} =$ _____

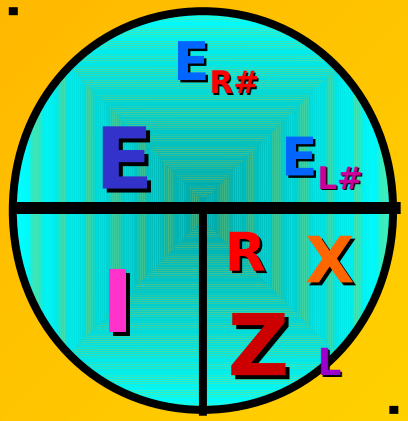
$E_{RT}^2 + E_{LT}^2 =$

Concepts

AC: Inductive Circuits

Calculate The Normal Operating Parameters. [**No** Rounding, Decimal 3 Places].





Period = 16.666 μS

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$2\pi F L_1 =$ $X_{L1} = 489.84\ \Omega$

$2\pi F L_2 =$ $X_{L2} = 979.68\ \Omega$

$2\pi F L_T =$ $X_{LT} = 1.469\ K\Omega$

$R_1 + R_2 =$ $R_T = 1.2\ K\Omega$

$\sqrt{R_T^2 + X_{LT}^2} =$ $Z_T = 1.896\ K\Omega$

$EA \div Z =$ $I_T = 63.29\ mA$

$I_T \times R_1 =$ $E_{R1} =$ _____

$I_T \times R_2 =$ $E_{R2} =$ _____

$E_{R1} + E_{R2} =$ $E_{RT} =$ _____

$I_T \times X_{L1} =$ $E_{L1} =$ _____

$I_T \times X_{L2} =$ $E_{L2} =$ _____

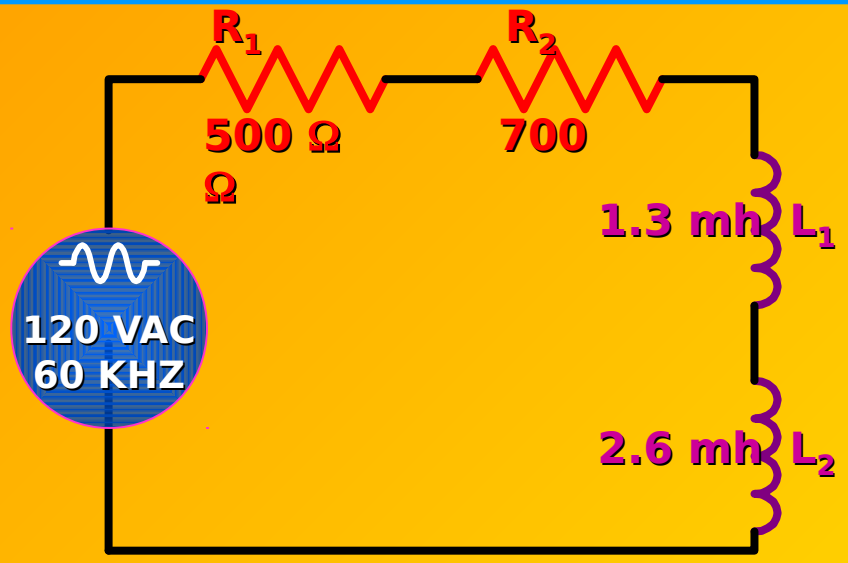
$\sqrt{E L_1 + E L_2} =$ $E_{LT} =$ _____

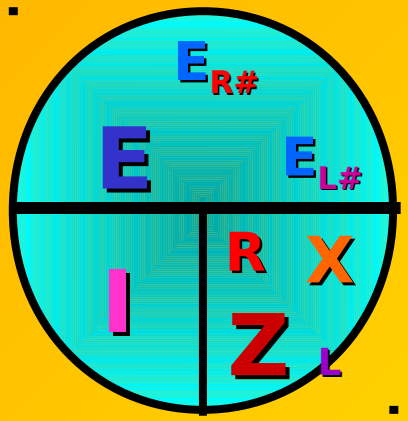
$E_{RT}^2 + E_{LT}^2 =$

ER 1,2,3

AC: Inductive Circuits

Calculate The Normal Operating Parameters. [**No** Rounding, Decimal 3 Places].





Period = 16.666 μS

PW = 8.333 μS

$2\pi F L_1 =$ $X_{L1} = 489.84\ \Omega$

$2\pi F L_2 =$ $X_{L2} = 979.68\ \Omega$

$2\pi F L_T =$ $X_{LT} = 1.469\ K\Omega$

$R_1 + R_2 =$ $R_T = 1.2\ K\Omega$

$\sqrt{R_T^2 + X_{LT}^2} =$ $Z_T = 1.896\ K\Omega$

EA ÷ Z = $I_T = 63.29\ mA$

$I_T \times R_1 =$ $E_{R1} = 31.645\ v$

$I_T \times R_2 =$ $E_{R2} = 44.303\ v$

$E_{R1} + E_{R2} =$ $E_{RT} = 75.948\ v$

$I_T \times X_{L1} =$ $E_{L1} =$ _____

$I_T \times X_{L2} =$ $E_{L2} =$ _____

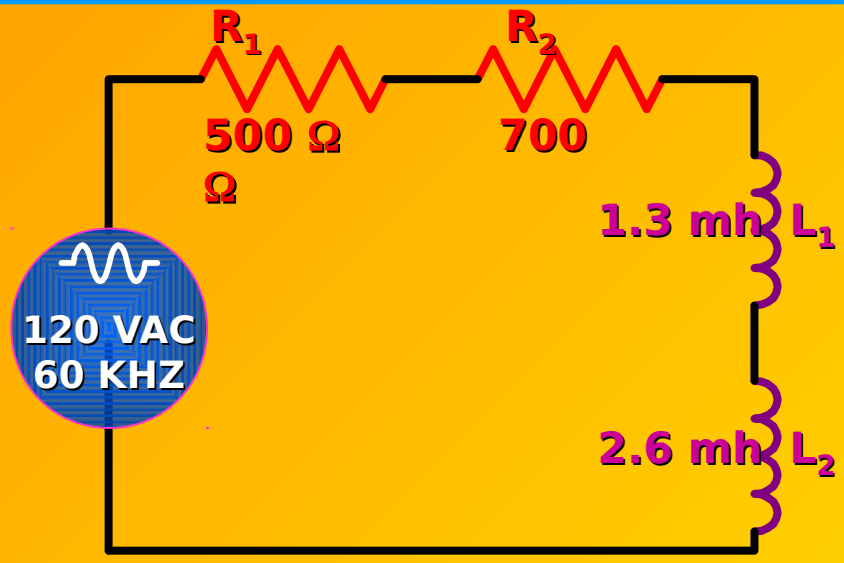
$\sqrt{E L_1 + E L_2} =$ $E_{LT} =$ _____

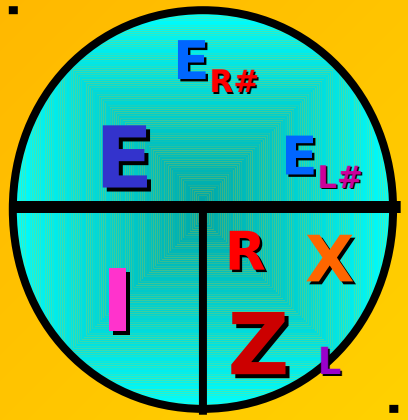
$E_{RT}^2 + E_{LT}^2 =$

EL 1,2,3,

AC: Inductive Circuits

Calculate The Normal Operating Parameters. [**No** Rounding, Decimal 3 Places].





Period = 16.666 μS

PW = 8.333 μS

$2\pi F L_1 =$ **X_{L1} = 489.84 Ω**

$2\pi F L_2 =$ **X_{L2} = 979.68 Ω**

$2\pi F L_T =$ **X_{LT} = 1.469 KΩ**

$R_1 + R_2 =$ **R_T = 1.2 KΩ**

$\sqrt{R_T^2 + X_{LT}^2} =$ **Z_T = 1.896 KΩ**

EA ÷ Z = **I_T = 63.29 mA**

$I_T \times R_1 =$ **E_{R1} = 31.645 v**

$I_T \times R_2 =$ **E_{R2} = 44.303 v**

$E_{R1} + E_{R2} =$ **E_{RT} = 75.948 v**

$I_T \times X_{L1} =$ **E_{L1} = 31.0 v**

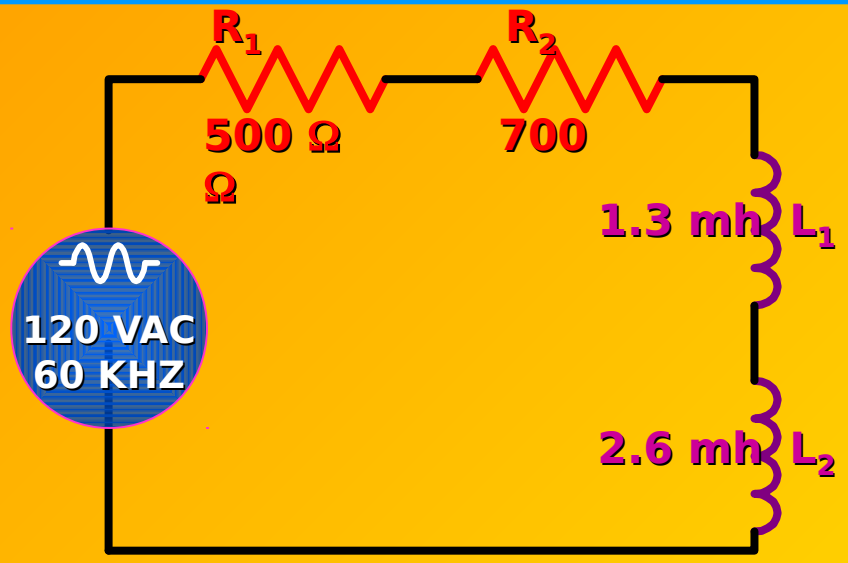
$I_T \times X_{L2} =$ **E_{L2} = 62.0 v**

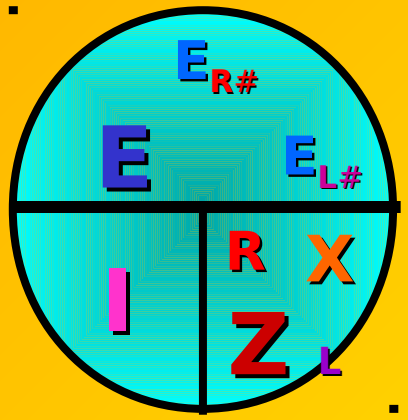
$\sqrt{E L_1 + E L_2} =$ **E_{LT} = 93.0 v**

$E_{RT}^2 + E_{LT}^2 =$ **EA**

AC: Inductive Circuits

Calculated Normal Operating Parameters. [**No** Rounding, Decimal 3 Places].





Period = 16.666 μS

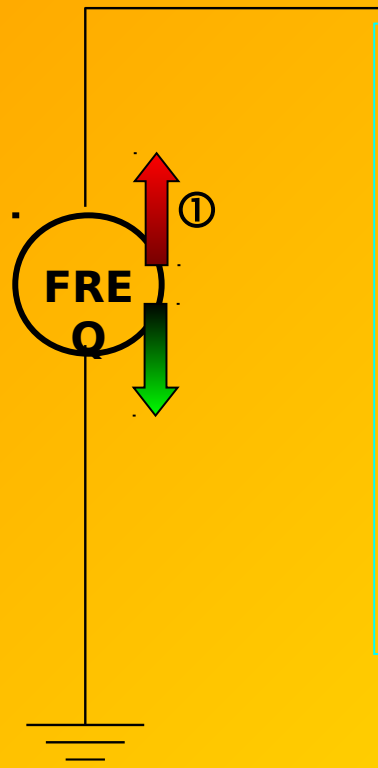
PW = 8.333 μS

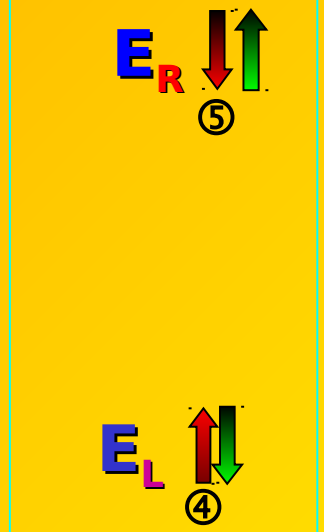
$2\pi F L_1 =$	$X_{L1} = 489.84\ \Omega$
$2\pi F L_2 =$	$X_{L2} = 979.68\ \Omega$
$2\pi F L_T =$	$X_{LT} = 1.469\ K\Omega$
$R_1 + R_2 =$	$R_T = 1.2\ K\Omega$
$\sqrt{R_T^2 + X_{LT}^2} =$	$Z_T = 1.896\ K\Omega$
EA ÷ Z =	$I_T = 63.29\ mA$
$I_T \times R_1 =$	$E_{R1} = 31.645\ v$
$I_T \times R_2 =$	$E_{R2} = 44.303\ v$
$E_{R1} + E_{R2} =$	$E_{RT} = 75.948\ v$
$I_T \times X_{L1} =$	$E_{L1} = 31.0\ v$
$I_T \times X_{L2} =$	$E_{L2} = 62.0\ v$
$\sqrt{E L_1 + E L_2} =$	$E_{LT} = 93.0\ v$
$E_{RT}^2 + E_{LT}^2 =$	

AC: Inductive Circuits

Relationship; As the <u>Frequency ⇑</u> the XL ⇑; if the <u>XL is ⇑</u> then the <u>EL is ⇑</u>.

If the EL has ⇑, then the ER must ⇑, [Kirchhoff Law].





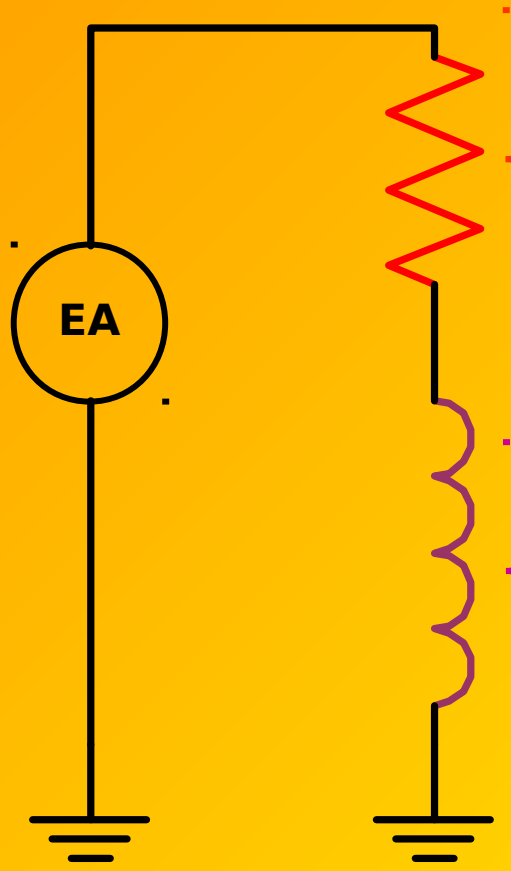
Direct Relationship Between the Frequency, XL & EL .

Indirect or Opposite relationship between the EL & ER .

Impedance: As Frequency ⇑, XL ⇑, Z ⇑. Resistance remains unchanged.

Open/Shorts

OPENS & SHORTS;



OPEN

$R_1 \uparrow = \infty\ \Omega$, $E_R \uparrow = 0$ A, Z $\uparrow$

SHORT

$R_1 \downarrow = 0\ \Omega$, $E_R \downarrow = 0$ v, Z $\downarrow$

$= X_{L1}$

OPEN

$L_1 \uparrow = \infty\ \Omega$, $E_L \uparrow = EA$, $Z \uparrow = \infty\ \Omega$

SHORT

$L_1 \downarrow$ $E \downarrow = 0$ v, Z $\downarrow$

$= R_1$

Note:
Actual Ohms Measurement will <u>normally</u> = **0 Ω, Voltage Drop** is a valid Check.

Phase Relationships

Phase Relationship;

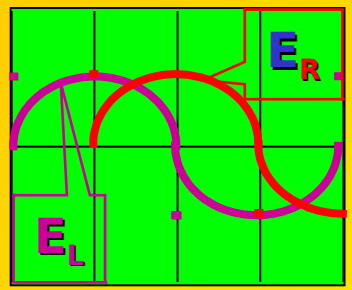
O-Scope with a 2 channel setup.

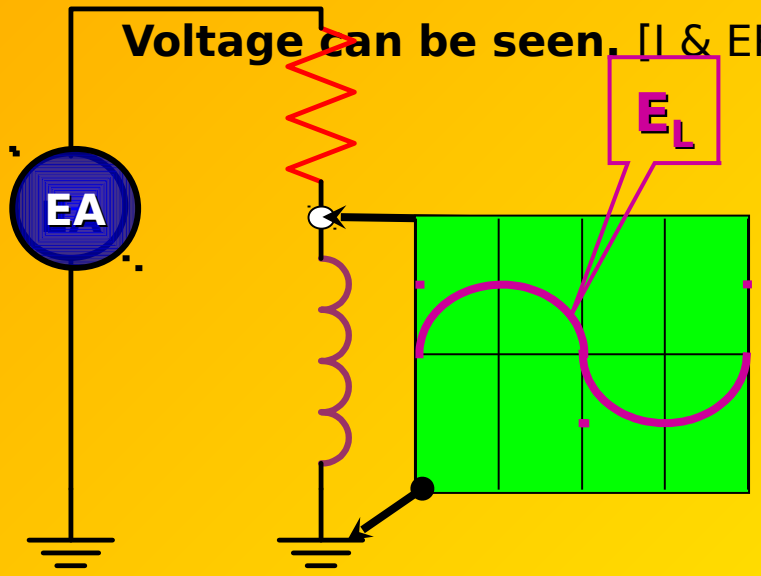
All Measurements are made in reference to GND.

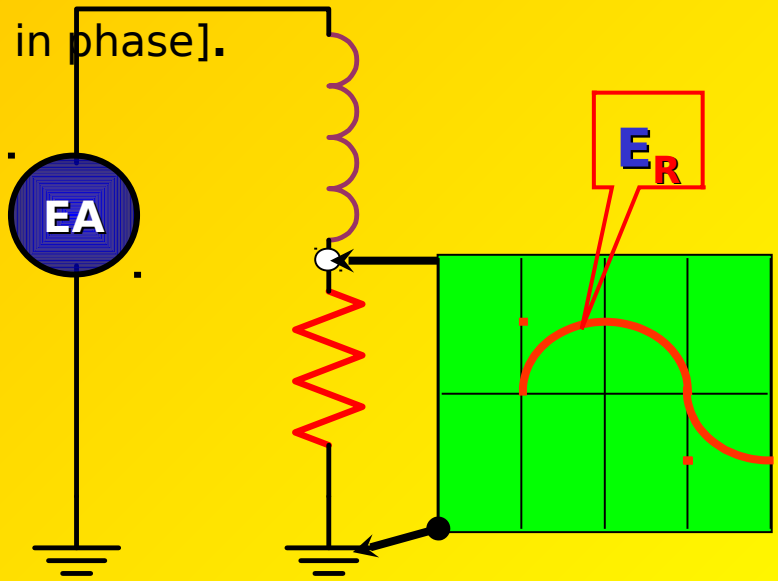
Point of reference, voltage across a resistor.

Current is not be seen on the O-Scope.

Voltage can be seen. [I & ER are in phase].







Problem Sheets

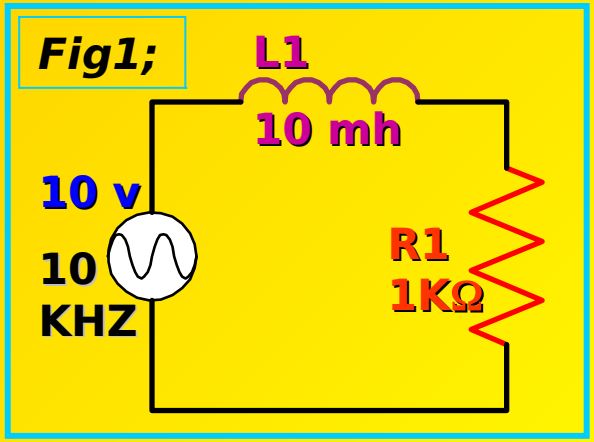
Problem Sheet;

1. The opposition to AC offered by an inductor is called ?

   A. Inductive resistor
   C. Inductance
   B. Resistance
   D. Inductive Reactance

2. What is the formula for computing inductive reactance?

3. Ref, *Fig 1*; Calculate Inductive Reactance. [XL] =



4. Ref, *Fig 1*; If R1 is shorted, what happens to the circuit Impedance?

   A. Increase
   C. Remains the same
   B. Decrease
   D. None of the above

Answers, 1-4

Problem Sheet;

5. One type of core used in inductors is air, the other is ?

   A. Paper B. Gold C. Iron D. None of the above

6. Ref, *Fig 2;* What is the Applied Voltage ? _____

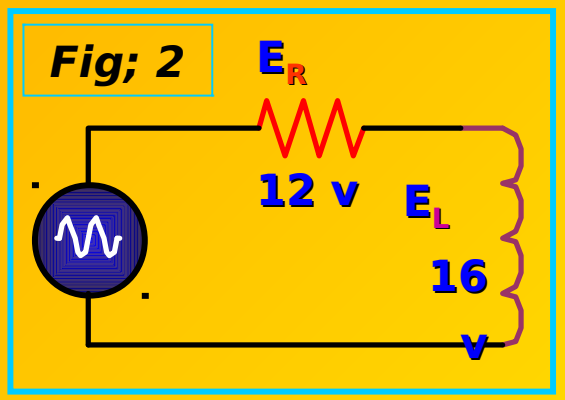
7. Ref, *Fig 3;* Calculate the total inductance.

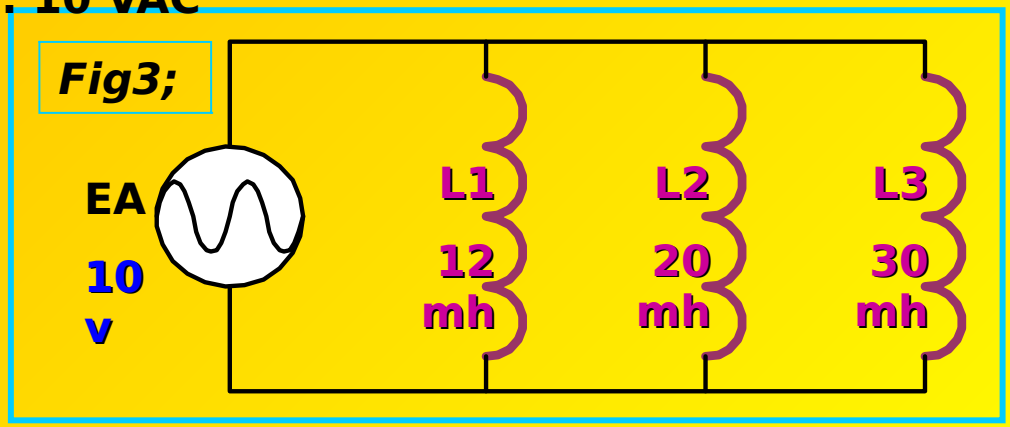
_____

8. Ref, *Fig 3;* If L1 were to open, what would be the voltage across L2 ?

   A. Zero volts C. One half of EA

   B. 5 VAC D. 10 VAC





Answers, 5-8

Problem Sheet;

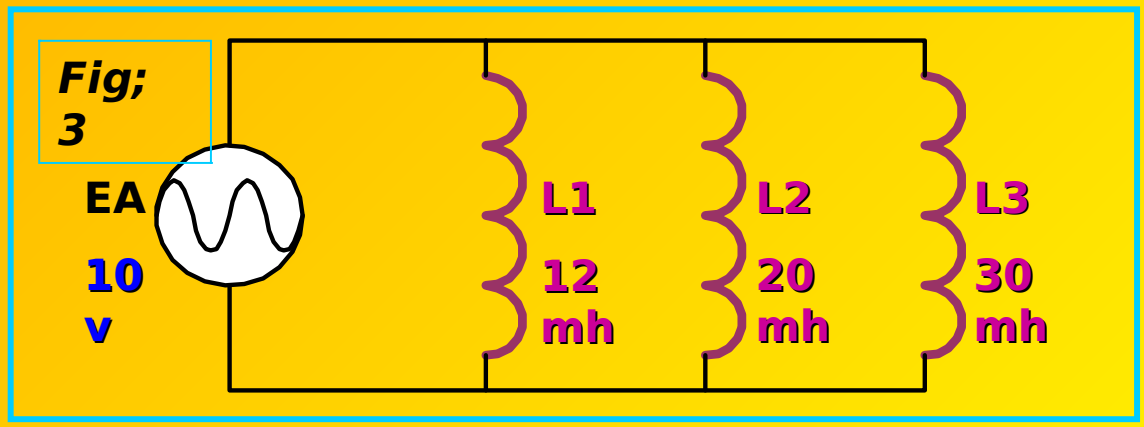
9. Ref, *Fig 3;* If L1 is shorted, what happens to the voltage drop across L3 ?

A. Increase

B. Decrease

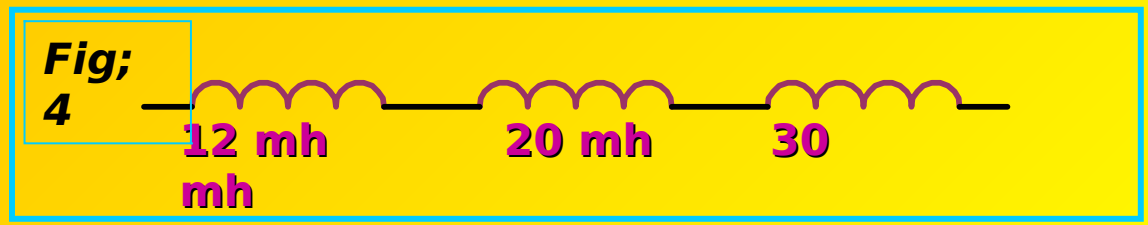
C. Decrease, not to Zero

D. Decrease, to Zero



10. Ref, *Fig4*; Calculate the total inductance.

_____



Answers, 9 & 10

Problem Sheet;

11. In an LR Ckt, [Inductor Resistor Ckt.] **the Current { *Leads*** or ***Lags* } the Inductor Voltage by { *180°* or *90°* } ?**

12. Ref, *Fig 5*; Calculate the total inductance.

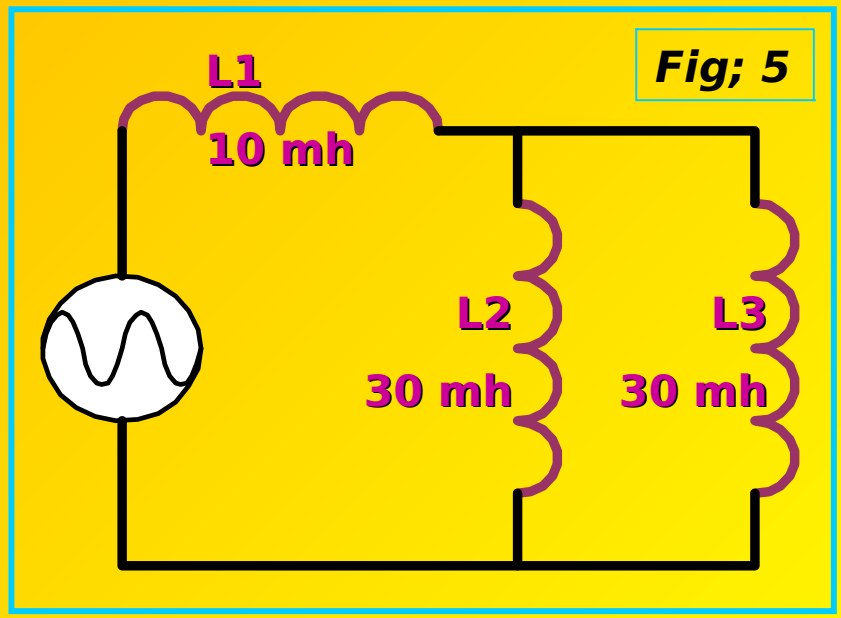
13. Ref, *Fig 5* ; If L1 is open, what happens to the voltage drop across L2 & L3 ?

A. 10 VAC volts

B. One half of EA

C. Zero

D. 20 Volts



Answers 11-13

Problem Sheet;

14. Ref, *Fig 5;* L2 is open, what happens to the [XLT] ?

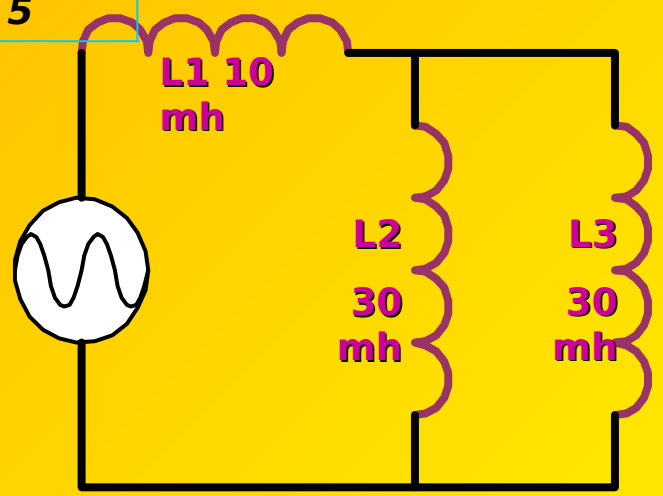
A. Remains the same

B. Increase

C. Decrease

D. Not enough info.

Fig; 5

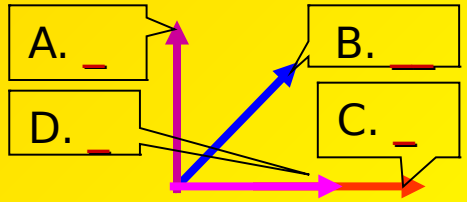


15. Label *Fig 6* as it refers to a series LR Ckt for I , ER, EL, EA.

16. What is the formula for calculating Impedance ?

_____

Fig; 6



Answers 14-16

Problem Sheet;

17. Ref, *Fig7*; Calculate the Impedance. Z = _____ .

18. Ref, *Fig 7*; Calculate the AC Current. I = EA ÷ Z I = _____

19. Ref, *Fig 7*; Calculate for E_R & E_L.

ER= IT X R1= ___ EL= IT X XL1=

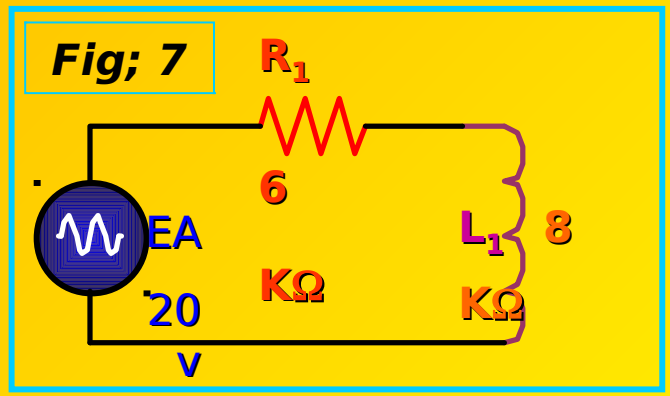
20. Ref, *Fig 7*; The applied frequency is increased. What effect does this have on Inductive Reactance [XL] ?

A. Increase

C. Decrease

B. Remains the same

D. Decreases EL



Answers 17-20

SUMMARY & QUESTIONS;

LESSON TEST;

Time; **20 Minutes.**

References; **Official OMEMS Training Aids.**

Standard; **70% minimum.**